Canada Alberta

**FOREST RESOURCE DEVELOPMENT AGREEMENT**
**ENTENTE SUR LA MISE EN VALEUR DES RESSOURCES FORESTIERES**

Canada Alberta

*The Canada-Alberta Forest Resource Development Agreement is a subsidiary agreement of the Canada-Alberta Economic and Regional Development Agreement, which provides coordination and cooperation between the governments of Alberta and Canada in areas of Alberta's economic development.*

*The Canada-Alberta Forest Resource Development Agreement is funded equally by the governments of Canada and Alberta, from April 1, 1984, to March 31, 1989.*

*Its primary objectives are to ensure the long-term availability of timber supplies; to optimize timber uses; and to contribute to the growth and diversification of Alberta's economy.*

*The Agreement comprises three programs: Reforestation; Applied research, technology transfer and opportunity identification; and Public information, evaluation and administration. These programs are managed by a joint Directorate and are implemented by the Canadian Forestry Service and the Alberta Forest Service.*

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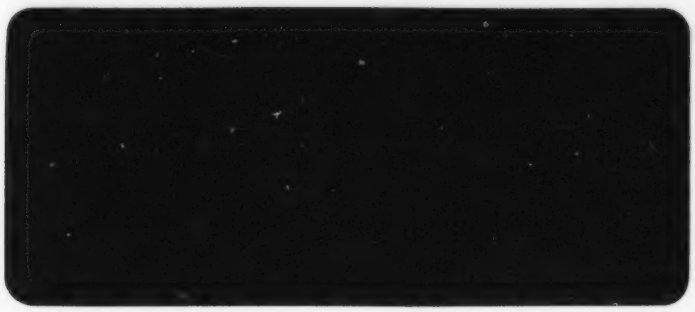

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# INNOVATIONS FOR HARDWOOD UTILIZATION: CATALYSED ORGANOSOLV PULPING AND SACCHARIFICATION

by

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1986

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# ENVIRONMENTAL, RAW MATERIAL AND MARKET CONSIDERATIONS IN UTILIZATION OF ALBERTA ASPEN:

# A CASE FOR ORGANOSOLV PULPING

by
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## SYNOPSIS

Primarily, pure and mixed aspen, poplar, birch and softwood raw materials can be effectively converted to fully bleached chemical pulps at high yield (>54%), ethyl alcohol and lignin by-products by the neutral alkali earth metal (NAEM) salt catalysed organosolv pulping process. Besides the high pulp yield and viable by-products, the process advantages include: small economies of scale, low capital investment, extremely low process water requirement, low pulp manufacturing costs, lack of environmental pollution and a high rate of return on investment.

The process requires funding for scaling up from bench scale by design and fabrication of pre-commercial equipment.

By slight modifications of the chemistry, the pulping process is converted into a highly efficient wood hydrolysis process which quantitatively decomposes wood into its chemical components of sugars and lignins. These basic feedstocks can be used in biological and chemical technologies leading to any or a combination of ethyl alcohol, acetone, butyl alcohol, propyl alcohol, phenols and aromatic hydrocarbon products to supply oxygenates and other liquid fuel chemicals into the growing liquid fuel markets. This industry would solely depend on forest and mill residues as its source of raw material and thus would not compete in any way but rather complement the traditional wood uses of lumber and pulp production. Process advantages include quantitative chemical (sugar and lignin) recoveries, small economies of scale, low environmental stress and high rates of return on investment.

Integration of organosolv pulping with organosolv wood hydrolysis would more than double the potential output of Alberta's forest. Due to the currently high interest in oxygenates (alcohol) as octane enhancers in gasoline in the USA, the additional revenue would have a substantial affect on the profitability of aspen processing to pulp and chemicals in Alberta as well as significantly stabilize these forestry operations in the future.

## INTRODUCTION

Aspen, balsam poplar and birch represent some 13.5 million $m^3$ or 40% of Alberta's potential annual yield of forest resources. Currently, only about 1% of this resource is used for the manufacture of products and natural decay of overmature timber (over 40 years of age) devours 10 to 20% of this wood volume per year. Assuming that the above annual cut represents about 30% of the total harvestable biomass (it is perhaps less), an additional 31.5 million $m^3$ of cellulosic biomass could be salvaged if commercial uses would be found to make use of the total growing biomass.

Constraints to aspen/poplar utilization have been extensively studied in recent past. The utilization potential of aspen has centered on reconstituted glued wood products such as waferboard, OSB and plywood and to a minor degree on the manufacture of dimension lumber. These uses are severely limited by the substantial variability of aspen stands, the long distance to large markets and the current limited size of the panel product and dimension lumber markets accessible to Canada.

Somewhat better and more obvious potential seems to exist for pulp and paper products. With new demands created by information explosion technologies (computers and telecommunication), writing and specialty papers showed 4 to 6% annual growth whereas the overall growth for pulp products continues at the rate 1.8 to 2% per annum. Of the current 50 million tonnes of world pulp and paper production, 25% (13 million T) originates from Canada. World pulp and paper demand is expected to grow to 100 million T/year by the year 2000 and if Canada is to maintain its share of the market a substantial new capacity will be required by that time. Increasing amounts of this new demand are supplied by thermomechanical and particularly short fibered (Eucalyptus and Gmelina) pulps from South America. Aspen pulps are expected to be fully competitive with these hardwood pulps in the future.

Constraints to establishment of a pulping industry in Alberta seem to be set by a number of factors such as: the excessive capital cost of economically viable pulp mills (>$400 million), environmental problems associated with water/wastewater usage/disposal, high transportation costs and distance from markets. These constraints can be overcome only if new, more efficient pulping processes are developed and introduced. To date, the high capital cost and environmental problems were responsible for the reluctance of close to half a dozen wood processing companies to build new grassroots pulping facilities in Alberta (and across Canada for that matter) during the past 15 years. The urgency for changing this situation cannot be overemphasized.

The forest and mill residue volume (31.5 MM $M^3$) associated with the annual allowable hardwood harvest in Alberta is sizeable indeed. Its utilization for wood chemical products is facilitated and encouraged by the fact that such use has no wood quality criteria and both decayed and sound wood residues have equal utility in the conversion process. Of the two major chemical product streams of sugars and lignin, sugars can be fermented into ethyl alcohol ( a liquid fuel and important industrial chemical) and the lignin can be processed to phenols suitable for manufacture of phenol formaldehyde resins, high capacity absorbents, and aromatic hydrocarbons. Development of these technologies and markets would significantly improve the otherwise very low wood utilization standard of hardwood forests, reduce the effective harvesting costs for hardwood logs and in general improve the profitability of forestry operations in Alberta.

## ORGANOSOLV PULPING AND SACCHARIFICATION: NEW DEVELOPMENTS

### A. Organosolv Pulping

Organosolv processing of wood to pulp and dissolved wood chemicals employs a water-miscible organic solvent, such as an alcohol or acetone and a suitable catalyst. Table 1 provides a broad summary of the various organosolv systems proposed in the past. Of these systems only a few are currently researched intensively with an aim toward commercialization. Published results on aspen, poplars and other comparable species are summarized in Table 2.

It is suggested, based on the summary in Table 2, that the pulp yield and chemical and physical/mechanical properties of the respective pulps and these parameters are a reflection of the capabilities of the processes listed indicating both their utility and economics. Thus a high pulp yield at low Kappa number (residual lignin content) and a high viscosity is desirable for best pulping results. For aspen pulps, Kappa numbers above 30 are considered high especially if the viscosity is also below 20 cP. The level of the strength properties (especially breaking length or tensile and tear) on the other hand are a reflection of the pulp's papermaking potentials.

A further important consideration of a new pulping process is its versatility with respect to production of various grades of papers and pulps and its flexibility with respect to adaptability to different wood species. Papermaking properties of pulp fibers have been effectively controlled by varying the pulping process by which the fibers were produced, similarly not all wood species can be pulped by the conventional pulping methods in use today.

Thus mixed species (hardwoods and softwoods) processing is a desired characteristic of a new pulping process especially if one considers that most northern hardwood forests contain various proportions of aspen, poplar and birch and occasionally softwoods (spruce, pine and fir). The best organosolv pulping method would be expected to treat all these species with nearly equal efficiency without the necessity for separating the chips of the various species.

On the basis of these considerations, only the Paszner/Chang NAEM catalysed organosolv pulping process fulfills all the conditions of short cooking time, high pulp yield at low lignin content and high pulp (cellulose) viscosity and high pulp strength. Other advantages of this process will become evident from the discussion which follows. Thus the NAEM catalysed organosolv process is capable of producing a bleachable grade aspen pulp in 30 minutes at a 63 yield having a Kappa number of 25 and a TAPPI 0.5%, CuEn viscosity of 50 cP. This pulp also has the highest sheet strength among all the pulps produced by the processes listed. These strength values were also confirmed by Professor Sarkanen at the Department of Forest Resources, University of Washington, Seattle.

With respect to the pilot plant facilities, the MD Papier process in West Germany is considered to be the furthest advanced as it operates a 100 kg/day continuous pulping pilot plant near Munich, West Germany. A 2 T/day pilot plant of a similar structure is currently under construction. This pilot plant being a miniature replica of a real organosolv pulp mill (complete with solvent and lignin recovery) is living proof that continuous chip feeding against the high pressures (34 bar at 195°C) is technically feasible without significant fiber damage.

## Pulping by the Paszner/Chang Process

Pulping of aspen by the Paszner/Chang process involves digestion of the chips in a closed pressure vessel at 190°C with a solvent composed of 80% methyl alcohol and 20% water in the presence of small amounts of alkali earth metals as a catalyst. The cooking times are under one hour and typically around 30 to 40 minutes. At the end of the cook the liquor is withdrawn and the chips disintegrated in the presence of excess solvent. The pulp fibers are washed with cooking liquor and sent to the bleach plant where they can be bleached by simple two- (D-P) or three-stage (C/D-E-H) sequences to up to 90% GE brightness. The cooking liquor which was withdrawn is allowed to expand and cool by flashing. On total removal of the methyl alcohol the dissolved lignin precipitates out as a fine powder leaving the dissolved sugars behind in the aqueous phase. Solvent removal and liquor re-circulation concentrate the sugars in the aqueous phase and following simple polishing they can be

fermented to ethyl alcohol. The residual methyl alcohol left behind in the aqueous phase is recovered along with the fuel grade ethanol.

Both softwood and hardwood pulps bleach with relative ease, the bleaching chemical requirements being commensurate with the residual lignin content (Kappa No.) of the pulps.

In comparative tests, strength properties of both bleached and unbleached hardwood and softwood pulps were found to be equal to those obtainable by the kraft process from the same species. Unbleached pulps required lixiviation, a process adapted by Paszner and Behera involving ion exchange of divalent ions ($Ca^{++}$ and $Mg^{++}$) for sodium with a mild acid wash followed by a soaking in mild alkali solution. Bleached pulps do not require lixiviation if the initial bleach step is carried out under acidic conditions. Alkali soaking of the chips before disintegration is beneficial and prevents excessive fiber damage due to the brittle nature of the fibers emerging from the 8% alcohol solutions.

The bleached fiber pulp is flash dried to produce a fluff pulp at 15 to 20% moisture content.

## Advantages of the NAEM Catalysed Organosolv Pulping Process

### (i) Yield

Perhaps one of the first and most obvious advantages of the NAEM catalysed pulping process is its capability to produce bleachable grade pulps at a wide range of yields (52 to 72%). The high pulp yields become possible because of the preferential topochemical effect and high initial delignification selectivity of the cooking solvent used. Detailed studies of the delignification process on NAEM catalysis revealed that initially lignin removal is restricted almost exclusively to the middle lamella holding the fibers together in the wood matrix. Thus even high yield pulps do not require refining and contain less than 0.2% rejects.

Conservatively calculated, in a 150 T/day bleached pulp mill every percentage point increase in the pulp yield between 43% (bleached kraft pulp yield) and 58% (NAEM catalysed aspen organosolv pulp, i.e., 15 percentage point increase in pulp yield between kraft and organosolv processing) represents $0.52 MM/percentage or a total of $7.8 MM in increased revenue to the mill per year. Therefore, a high bleachable pulp yield is economically most important and the relatively low bleached pulp yield of the kraft process (38 to 43%) has long been criticized as inadequate in the past. The higher pulp yields (as compared to the other organosolv processes) in the NAEM catalysed process are believed to be due to the mild catalytic

delignification (pH 4.2) afforded by the neutral catalysts used and the high (80%) alcohol concentration in the cooking liquor. Thus it was found that the selectivity of alcohol solvents for lignin decreases with increasing water content in the cooking liquor.

It is thus obvious that the NAEM catalysed process yields some 20 to 35% more saleable pulp than the kraft process.

(ii) **Capital Cost**

Due to process simplicity, lack of complicated chemical recovery and pollution abatement equipment requirements, organosolv pulp mills are expected to cost only one-third as much to construct as kraft mills for comparative pulping capacities. Detailed calculations show that while the legendary minimum capacity kraft pulp mill (700 T/day) will cost around $400 MM to construct, the same capacity NAEM catalysed organosolv mill will cost only $126 MM to build. Sensitivity analysis also shows that the minimum economical capacity of an organosolv pulp mill is around 80 to 100 T/day and would cost only $35 MM. The advantages of such a small pulp mill are multifold, one of which is that smaller, sustained yield forest areas can readily supply the wood requirements in perpetuity without facing long hauling distances for wood collection. At the same time the option also exists to base such small mills entirely on chip supplies produced by sawmills within a reasonable proximity thus eliminating the costly woodroom expenditures (log booming, sorting and chipping).

The small economies of scale of pulping therefore significantly affect the capital cost necessary for establishing a pulp mill, whereas at the same time assure increased profitability and competitiveness of the industry on international markets.

(iii) **Environmental Considerations**

Both sulphite and kraft chemical pulping processes suffer from extensive air and water pollution due to the presence of and necessity to recover the sulphur compounds from the spent cooking liquors. Up to 45 to 50% of the capital cost for erection of kraft mills is dictated by chemical recovery and pollution abatement. About half of this expenditure (or $100 MM in case of a minimum economical capacity kraft mill) must be considered as non-productive and must be laid out to secure compliance with environmental laws.

Further, the effluent load from bleached kraft mills is between 5,000 to 15,000 T per tonne of bleached pulp. This amount of effluent requires treatment before discharge to eliminate its BOD and toxity before it can be returned into the waterways.

For both of these considerations the organosolv process shows considerable advantages. Since organosolv cooking liquors do not contain sulphur and the NAEM salts are environmentally harmless (the oceans and fresh water supplies contain substantial quantities of calcium chloride, magnesium chloride and magnesium sulphate) the effluents of the NAEM catalysed organosolv process do not require extensive treatment before discharge. It is anticipated that the organic loads will be largely recovered in the form of by-products from the pulping liquor.

At 60% moisture content of the wood chips, about one tonne of water is contributed to the cooking liquor by the wood. At a liquor to wood ratio of 7:1 and liquor composition of 80% alcohol and 20% water, the water requirement for the process, including pulp washing, is 0.4 T per tonne of pulp produced. The two-stage organosolv pulp bleaching will require less than 2 T of water per tonne of pulp bleached. Since solids (sugar) concentrations in both pulping and bleaching liquors will be high (>16%), recovery of the dissolved degradation products will become possible especially if the effluent waters will be used for steam generation for the plant and further concentration to that automatically obtained on removal of the organic solvent (alcohol) will take place.

By these considerations, both the water supply criteria and effluent disposal problems are grossly minimized with organosolv pulp mills due to the fact that 80% of the process liquor is made up of alcohol which is recovered and extensively recycled. The absence of sulphur from all stages of pulping makes solvent and by-products recoveries (lignin precipitation, sugar fermentation and organic acid recovery) very simple and inexpensive indeed.

### (iv) By-product Recoveries

Theoretically, sugars and lignin are the major by-products of pulping with small amounts of acetic acid and methanol also occuring. Bleach plant effluents contain mono- and dicarboxylic acids as oxidation products of lignin.

Sugar and lignin utilization as by-products of the pulping process has long been practiced by the sulphite pulp industry. However, less than 10% of the total world pulp production is made by this process today.

In the kraft process, the sugars are degraded to isosaccharinic acid in the alkali liquor, their reconversion to fermentable sugars is difficult and the recovery from the spent liquor would seriously disrupt both the energy and cooking chemical recoveries of this process. Similarly, lignin recovery from the kraft black liquor requires acidification, a process both costly and disruptive of the energy and cooking chemical recoveries from the spent liquor.

Energy self-sufficiency is largely predicated on the burning of the black liquor organic solids (sugars and lignin) and although it can be shown that the cost of this form of energy is the most expensive energy money can buy (about $7.8/MM Btu), the laws of economics are completely ignored by the industry.

In organosolv pulping, by-product recovery is an incidental benefit of the solvent (alcohol) recovery. On flashing the cooking liquor, the lignin is automatically precipitated out in a granular powderous form. The sugars remain dissolved in the aqueous phase and can be readily transferred into a fermentable state with a minimum of effort. Due to the extensive solvent recirculation between the organosolv pulping stages and removal of the organic phase (distillation of the alcohol) sugar concentrations up to 30% are reached and these allow for use of the most energy efficient fermentation/distillation process known today.

In a 150 T/day NAEM catalysed organosolv pulp mill, the by-product credits from lignin and ethanol sales exceed the total value of the raw materials (wood, catalyst, solvent and bleaching chemicals) and thus can contribute significantly to the excellent economics of the process (Table 4). Lignin utilization is expected to reach commercial levels as a result of organosolv developments. Lignin constitutes up to one-third the mass of wood and thus substantial quantities will become available on commercialization of the organosolv process. Organosolv lignins are known to be free of contaminants (sugars and metal ions), have high solubility in organic solvents because of their low molecular weight ($\overline{M}_w$=1200 - 2800) and high reactivity in various chemical applications. Through appropriate treatments better than 50% and up to 70% of the phenol can be replaced in phenol-formaldehyde resins whereas large quantities of lignin could be marketed as industrial (metal) absorbents, aromatic liquid fuels, phenols and solvents. The question of lignin utilization, though currently studied very intensively, is largely unsettled. The value of lignin ranges between $60/T to as high as $950/T depending on the end use. Marketing of the lignin by-product therefore is expected to contribute substantially to the economics of organosolv pulping.

### (v) **Sheet (Paper) Properties**

Recent studies by Paszner and Behera (Holzforschung, 1985) have shown that organosolv pulps following lixiviation (cation exchange and alkali treatment) had equivalent strength to similar kraft pulps.

With aspen pulps a breaking length (tensile) of 11.3 km and a tear factor of 70 to 80 can be achieved. There are indications that in admixtures with birch even these values could be exceeded and that such pulps would be fully competitive with European beech and South

American (Brazilian) eucalyptus pulps. The production costs of aspen organosolv pulps would be substantially lower especially if manufactured in optimum (400 T/day) rather than minimum capacity (100 T/day) mills.

In summary, based on the currently available knowledge on organosolv pulping, this new technology excels in both technological and economic terms and is expected to open up vast opportunities in processing and marketing the unused aspen resource of Alberta.

## B. Wood Waste Processing by the Acid Catalysed Organosolv Saccharification ( ACOS) Process

Up to 70% of the primary wood biomass ends up in one form or another in waste. Its utilization could greatly contribute, double or triple, not only the degree of resource exploitation, but also increase the profitability of primary wood (lumber and pulp and paper) production. The lack of wood quality criteria for this application makes wood waste an excellent raw material.

Traditional technologies, weak and strong acid hydrolysis and gasification as well as the newer technologies of enzymatic hydrolysis and steam explosion failed to provide economically viable alternatives for converting wood waste into ethanol. The problems with these technologies are well documented in literature.

Organosolv saccharification represents basically the same technology as described earlier for pulping by Kleinert and others, however we have refined the technique by judicious selection of the conditions under which rapid hydrolysis of cellulose and dissolution of the lignin, and indeed that of wood, occurs. The Kleinert process was optimized for maximum fiber production whereas the ACOS process is optimized for maximum hydrolysis.

During the process of investigations it was found that, in the presence of an acid catalyst, acetone rapidly complexes at high temperature with the carbohydrates in the wood matrix even in the presence of water, causing its rapid and quantitative disproportionation into monomeric sugar derivatives (isopropylidenes) and a largely depolymerized natural lignin product. The sugar derivatives can be quantitatively decomposed to recover the reducing sugars and the solvent (acetone). Total hydrolysis times as short as 30 seconds are sufficient to decompose 95% of the cellulose substrate at 220°C and allows for theoretical recovery of the sugars in a fermentable (reducing) form on working up the hydrolysate. In kinetic terms the ACOS process is up to 700 times faster than the aqueous weak acid process (eg. Madison) which is 100 times the acid concentration that is used for the ACOS process.

Technologically, the ACOS process shows many similarities to the NAEM catalysed pulping process, the difference being that in the ACOS process the reagents and process conditions are selected in such a way that total decomposition (hydrolysis and dissolution) of wood is obtained within the digester proper within the given hydrolysis time. Recovery of cellulose (a microcrystalline cellulose) is only an option and can be obtained by interrupting the hydrolysis process at around 70% weight loss of the feedstock. In pulping, on the other hand, the conditions are so selected as to minimize the hydrolytic attack on the carbohydrates (hemicelluloses and cellulose) to secure maximum pulp yield.

Solvent, lignin and sugar recoveries for the ACOS process largely duplicate those described for recovery of the by-products from the spent pulping liquor as described above. Characteristically, however, due to the more rapid hydrolysis rates in the ACOS process, the concentration of sugars in the aqueous phase after evaporation of the solvent (acetone) reach between 30 to 50% depending on the solvent to substrate ratio used. In spite of the high hydrolysis temperature (180 to 220°C) no furfurals were detected in the hydrolysis liquors due to the protective effect of the complexes, and the low acid concentration (0.005 M) used.

As indicated above, the sugar recovery exceeds 95% of the theoretical. Thus the ethanol yield from aspen wood calculates to about 480 L/T if simultaneous xylose/hexose fermentation is practised as became possible recently by the new BIOSTIL process. The process also recovers about 170 kg of powdered lignin, some methanol and mixed phosphates if phosphoric acid is used as an acification catalyst for the secondary hydrolysis phase where the sugar/acetone complexes are destroyed.

Feasibility and economic calculations indicate that the required non-credit rated ethanol selling price will vary between $0.503/L for a 100 T/day (16,000,000 L/year) capacity plant to $0.260/L for a 1000 T/day (158,400,000 L/year) plant. By-product credit rated ethanol selling prices for the same capacities calculate to $0.378/L and as low as $0.135/L, respectively. Medium capacity plants at 300 T/day should be able to produce ethanol at $0.20/L when the lignin selling price is fixed at $150/T. A sample calculation of the ethanol production costs for 300 T/day capacity plant using a mixed sawdust feed is provided in Table 4. Capital costs calculate to $13.5 MM at 100 T/day to $53.5 MM at a 100 T/day capacity. At the current $0.63/L price for ethanol, plants as small as 100 T/day (16,000,000 L/year) feedstock consumption seem to be economically viable.

To confirm the technical and economical predictions a pilot plant of 100 L/day capacity is currently under active testing in Brazil. Plans for an ACOS 5000 (5000 L/day) pre-commercial plant (1,750,000 L/year) is in the advanced planning stage.

## SUMMARY

Under the prevailing economic and industrial conditions, both paper products and liquid fuels are expected to represent good potentials in large volume marketing of aspen in the future. The long term viability of such a scheme is largely predicted on the fact that pulp and paper and liquid fuel production from aspen and other associated species will present new directions of utilization of Alberta's forest resources. Integrated production of pulp and paper and fuel ethanol is considered to be a highly compatible means of aspen utilization since it provides the means for 100% utilization of the growing biomass without restrictions as to the quality of the raw material supply. Therefore, integrated production of pulp and wood chemicals (ethanol and lignin) by organosolv means suggests itself as an attractive means to maximize the value of the unused Alberta hardwood resource.

In terms of these products, the current 13.5 MM $m^3$ (3.375 MM T) allowable prime timber volume is worth $1.2 billion when converted to bleached pulp. It is anticipated that about three times this volume or 31.5 MM $m^3$ (7.87 5 MM T) woodwaste is associated with the above allowable prime wood production. This biomass represents $2.15 billion when converted to ethyl alcohol with an associated $367 MM in lignin sales. The total value of the converted aspen resource is $3.717 billion annually. No doubt, both injection of such revenues and creation of jobs required for such conversion would have a very significant effect on the provincial economy in the future.

# Table 1.
# MAJOR ORGANOSOLV PULPING SYSTEMS

| SOLVENT | CATALYST |
|---|---|
| ETHYL ALCOHOL ..... | HCl, NaOH, $NH_3$, $Al_2(SO_4)$, $AlCl_3$, $(NH_4)_2S$, $NaHCO_3$+ MAQ, HCOOH |
| METHYL ALCOHOL ..... | $CaCl_2$, $MgSO_4$, NaOH, $SO_2$, Oxalic acid, Salicylic acid, Kcl/HCl |
| i-PROPYL ALCOHOL ..... | $NaHSO_3$, $Na_2SO_3$ |
| BUTYL ALCOHOL ..... | $HNO_3$, AQ |
| ETHYLENE GLYCOL ..... | $Al(SO_4)_3$, $AlCl_3$, |
| PHENOL ..... | HCl |
| CRESOL ..... | - |
| FORMIC ACID ..... | - |
| ACETIC ACID ..... | - |
| ACETIC ACID/ETHYL ACETATE | - |
| ACETONE ..... | HCl, $NH_3$ |
| M.E. KETONE ..... | - |
| CYCLO HEXANONE ..... | $NH_3$ |
| DIOXANE ..... | HCl, $H_2SO_4$ |
| SULFOLANE ..... | $Na_2S$, $H_2SO_4$ |
| DMSO ..... | $SO_2$, $NO_2$, $H_2SO_4$ |
| 1,6 HEXANEDIAMINE ..... | - |

# Table 2.

## COMPARATIVE RESULTS ON ORGANOSOLV PULPING OF ASPEN

| PROPONENT | SOLVENT | CATALYST | SPECIES | TEMP. °C | TIME min | YIELD % | KAPPA No. | VISCOSITY cP | STRENGTH PROPERTIES AT 500 mL CSF | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | BREAKING LENGTH, km | BURST FACTOR | TEAR FACTOR | |
| KLEINERT | 50% EtOH | - | Aspen | 190 | 120 | 52 | 15 | 22 | 7 100 | 50 | 78 | At 500 mL Csf<br>Select hardwoods only |
| MD PAPIER (W. GERMANY) | A.60% EtOH<br>B.50% EtOH | -<br>NaOH | Poplar | 185 | 45 | 56<br>46 | 67<br>35 | 26 | 7 500 | NA | 66 | Softwoods and hardwoods |
| BEG/KATZEN<br>(Alcohol Pulp Recovery) | 50% EtOH | - | Aspen | 190 | 150 | 55 | 27 | 32 | 7 300 | 50 | 66 | Bleached (80% strength<br>Select hardwoods only |
| PASZNER/CHANG<br>(Catalyzed Organosolv) | 50% MeOH | $CaCl_2$ | Aspen | 190 | 50 | 62 | 10 | 50 | 11 000 | 60 | 71 | All lignocellulosics |
| BATTELLE (Phenol Pulping) | 40% Phenol | HCl | Birch | 190 | 240 | 42 | 14 | 50 | 7 500 | 42 | 66 | Softwoods and hardwoods |
| JAPAN PPRI (Cresol Pulping) | 50% Cresol | - | Beech | 185 | 300 | 55 | 25 | 10 | 6 500 | 55 | 60 | Report on beech only |
| YOUNG (Ester Pulping) | 50% HAc<br>50% EtAc | - | Aspen | 170 | 150 | 48 | 10 | NA | NA | NA | NA | Hardwoods, lower yield on softwoods |

# Table 3. ORGANOSOLV PULP PRODUCTION ECONOMICS

**PLANT DESCRIPTION**

**PRODUCTION:** **PULP:** 150 TPD (49 500 TPY) Bleached Pulp.
Pulp Yield 63%, Kappa No. 25, Bl.Y.: 58.3%

**LIGNIN:** 13 700 TPY

**SUGARS:** 13 218 TPY

**(ETHANOL:** 6 084 TPY; 7 665 450 L/Y)

**CAPITAL COST:** $ 50 000 000

| Item | Quantity | Unit cost | TOTAL |
|---|---|---|---|
| RAW MATERIALS | | | |
| Wood Chips, T | 84 905 | 45 | 3 820 755 |
| Catalyst, T | 400 | 300 | 120 000 |
| Solvent Make-up, T | 743 | 260 | 193 180 |
| Bleaching Chemicals, T | 1 485 | 650 | 965 250 |
| ENERGY | | | |
| Steam, T | 490 000 | 9 | 4 410 000 |
| LABOR | | | |
| Operating | 15 | 25 000 | 375 000 |
| Supervisory | 3 | 40 000 | 120 000 |
| Overhead @ 30% | | | 148 500 |
| MAINTENANCE (3% of TCI) | | | 1 500 000 |
| CAPITAL CHARGES ( 0. 2153 of TCI) | | | 10 756 000 |
| TAXES & INSURANCE ( 2% of TCI) | | | 1 000 000 |
| **TOTAL OPERATING COST** | | | $ 23 408 685 |

**PRODUCTION COST** $ 23 408 685 : 49 500 = $ 472/T

**BY-PRODUCT CREDITS** (18 612x150)+(6 084x620) = $ 5 827 080

CREDIT-RATED PRODUCTION COST: $ 17 581 161:49 500= $ 355/T

**PROFITS** 49 500 x $ 625 = $ 30 937 500

Less Production Costs: $ 17 581 161

NET PROFIT: $ 13 356 339 (CDN)